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Narrow Line X-Ray Calibration Source for High Resolution Microcalorimeters

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Abstract We are developing a narrow line calibration source for use with X-ray microcalorimeters. At energies below 300 eV fluorescent lines are intrinsically broad, making calibration of high resolution detectors difficult. This source consists of a 405 nm (3 eV) laser diode coupled to an optical fiber. The diode is pulsed to create approximately one hundred photons in a few microseconds. If the pulses are short compared to the rise time of the detector, they will be detected as single events with a total energy in the soft X-ray range. Poisson fluctuations in photon number per pulse create a comb of X-ray lines with 3 eV spacing, so detectors with energy resolution better than 2 eV are required to resolve the individual lines. Our currently unstabilized diode has a multimode width less than 1 nm, giving a 300 eV event a FWHM less than 0.1 eV. By varying the driving voltage, or pulse width, the source can produce a comb centered on a wide range of energies. The calibration events are produced at precisely known times. This allows continuous calibration of a flight mission without contaminating the observed spectrum and with minimal deadtime.

Keywords Microcalorimeters · Calibration · Fiber-optics · Lasers · X-ray detectors

1 Introduction

We are currently developing an array with 1 eV FWHM in the few hundred eV range for the study of astrophysical plasmas near 10^6 K [1]. 1–2 eV FWHM is needed even for line identification in this spectral range, but there is no way of verifying this resolution with fluorescent line calibrators. The atomic fluorescent lines normally used for in situ

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Table 1 Performance requirements for the laser diode for different applications

Mission type	X-ray energy (eV)	Detector resolution (FWHM eV)	Requirements: Calibrator accuracy requirements (eV)	Requirements: Line width requirements (FWHM eV)	Long term stability: Δλ (nm)	Long term stability: Δf (GHz)	Laser line width: Δλ (FWHm nm)	Laser line width: Δf (FWHm THz)
Rocket EXP	300	1	0.1	0.2	0.14	250	3	5
IXO-Class	6,000	2	0.02	0.4	0.0014	2.5	1.2	2

calibration are much too broad at low energies where the upper levels in the transition are involved in chemical bonding. At higher energies even the well-isolated 5.9 keV Mn K_α line popularly used for evaluating X-ray detectors is so much broader than the best current detectors that it is very difficult to determine their resolution precisely.

The high spectral resolution combined with high throughput of cryogenic microcalorimeters promises to revolutionize X-ray astronomy. However, achieving high performance with these detectors requires calibration with matching precision and this is becoming increasingly difficult at the present state of the art. The excellent line profiles and high throughput of these detectors allows line centroids to be determined to a small fraction of the detector resolution, making sensitive measurement of Doppler shifts possible if the absolute energy calibration is comparably well determined. Line width measurements give valuable astronomical information on thermal and turbulent broadening but require accurate knowledge of the detector line profiles. Observations normally extend over long periods of time where orbital conditions vary and produce small changes in detector performance, so in situ calibration is required. Large laboratory monochromators have the necessary performance and are used for calibrations on the ground, but flying these instruments is not feasible. Table 1 shows ideal calibration requirements to maximize the performance of rocket [1] and IXO-Class [2] missions and the laser characteristics that will meet them.

The pulsed diode source is also very useful for generating the large amount of calibration data needed for preparing optimal filters for nonlinear detectors with non-stationary noise [3]. Events can be provided over a wide range of evenly spaced energies, and eliminating sampling phase error by synchronizing the events with signal digitization greatly simplifies the processing.

2 Construction and Operation

The laser diodes are the type used in 'Blu-Ray' optical disk players. Readily available sources do not provide well characterized devices, but most of the diodes we have obtained appeared similar and were usually rated at 20 mW. As supplied, they run multimode, and we checked to be sure the FWHM was less than 1 nm. An optical fiber is glued to the glass window of the diode using a clear epoxy (see Fig. 1). The fiber is used to transmit the light from the room temperature stage of the dewar through the colder stages as shown in Fig. 2. An infrared filter mounted to the 4 K shield

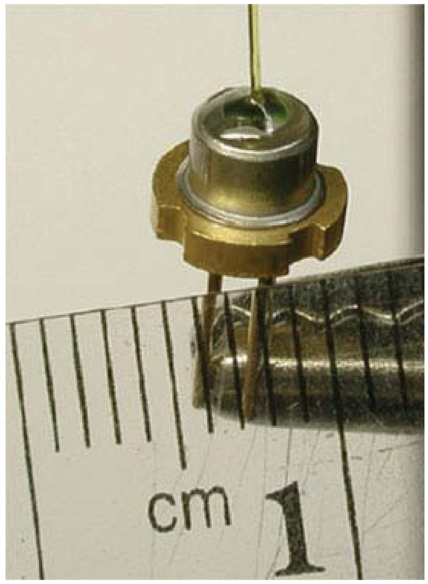

Fig. 1 Laser diode with the optical fiber attached. (Color figure online)

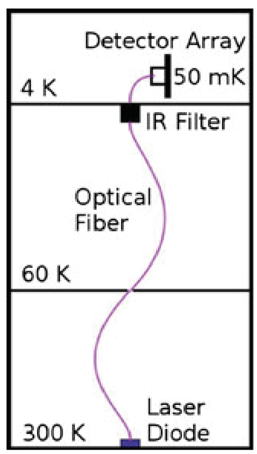

Fig. 2 Current configuration of the laser diode, optical fiber and infrared blocking filter in the dewar. (Color figure online)

blocks any propagating thermal photons coupled into the fiber or generated in it in the warmer parts of the dewar. The filter uses an infrared reflecting mirror and an infrared absorbing filter in series. Both filters cut off at a wavelength of 750 nm. No lenses are used, resulting in a geometrical loss of about 10^{-3} in feeding the output fiber. The optical fiber has a 250 μm silica core. As long as an infrared filter is present the type of fiber is not critical. The diode is pulsed to create a short burst of light with a total absorbed energy equivalent to a soft X-ray photon. The pulses need to be shorter than the rise time of the detectors in order for the pulse to have the same effect as one X-ray photon. In the present test setup, about 2 eV is incident on each pixel per nanosecond of pulse width. Figure 3 shows the open loop wavelength stability of our laser diode. It is adequate for the rocket experiment, but would have to be externally stabilized for an IXO-class application.

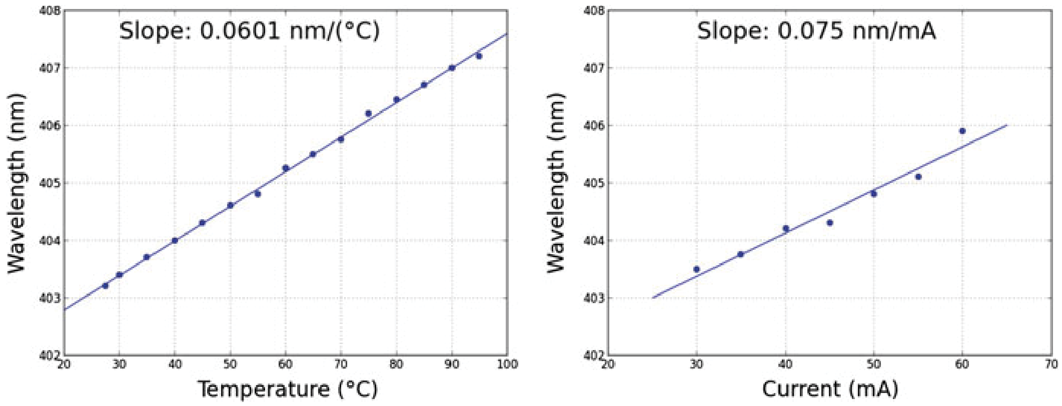

Fig. 3 Wavelength stability of the diode versus temperature (*left*) and current (*right*). (Color figure online)

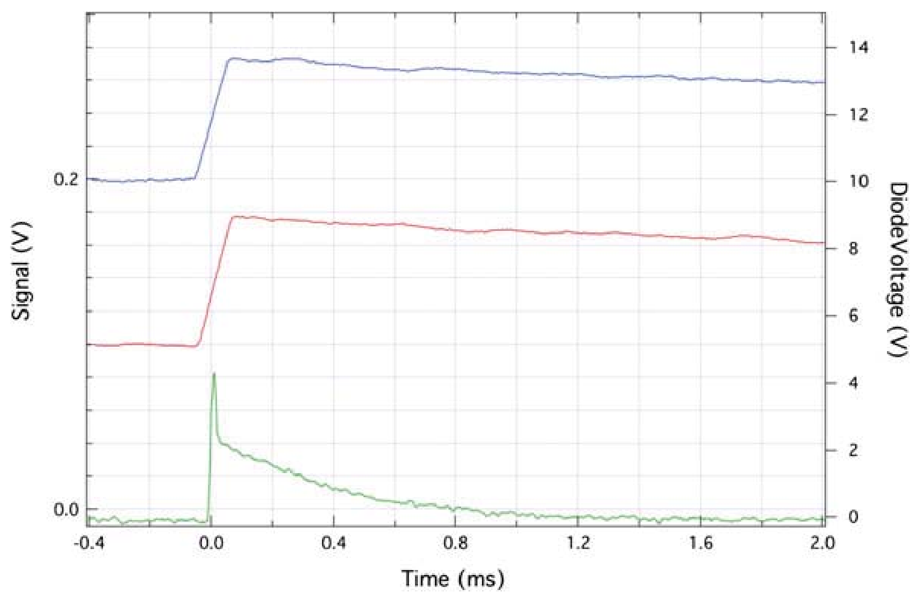

Fig. 4 *Top* 6 keV Mn K_α X-ray, *middle* 6 keV diode pulse, *bottom* voltage pulse across the diode. The voltage pulse tail is below the threshold of the diode and contributed no light. The voltages are offset for comparison. The traces were DC coupled and triggered off of the detector signal. (Color figure online)

3 Results and Conclusions

Figure 4 shows a 6 keV X-ray and a large diode pulse taken with a transition edge sensor at the University of Wisconsin. The X-ray photon and diode pulses are indistinguishable. Figure 5 shows the pulse height spectrum obtained at Goddard Space Flight Center with a comb centered at about 12 eV on a high resolution TES array. The detector is a Au/Mo transition edge sensor with $80 \times 80 \times 3.22\ \mu$m gold absorbers that have less than 30 % reflectance at 405 nm [4]. It has a baseline FWHM of 0.75 eV. Tests are continuing with larger photon numbers to find the source of the low energy shoulders which are causing the broadening of the calibration lines at higher energies.

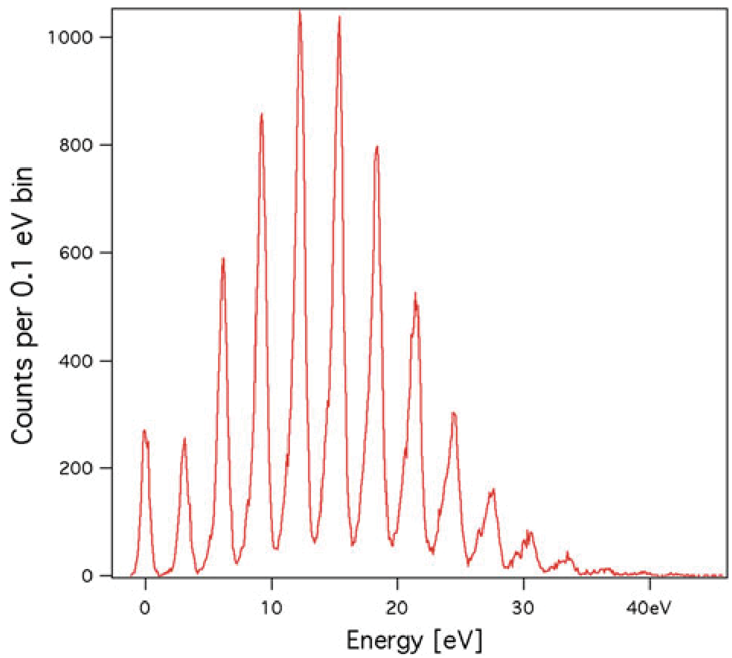

Fig. 5 Pulse height spectrum from the laser diode using a high resolution array and small pulses. (Color figure online)

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